

James Webb Space Telescope (JWST)

Mid-Infrared Instrument (MIRI)

MIRI Detector Requirements Document

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DOCUMENT LOG

Issue	Date	Pages Affected	Description

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1. Overview

This document details the requirements and goals for the sensor chip assemblies (SCAs) to be used in the James Webb Space Telescope (JWST) Mid-InfraRed Instrument (MIRI). MIRI is to be a combination imager and spectrometer with the following modes:

- Imaging from 5-28 μm with a variety of fixed filters over a 1.5 arcmin field-of-view
- Coronagraphy for high spatial resolution, high contrast studies
- Low resolution ($R = 100$) grism spectroscopy, emphasis on 5-10 μm
- High resolution ($R \sim 2000$) grating spectroscopy, 5-28 μm

The first three modes will utilize one individual detector array; high resolution spectroscopy will employ an additional two detector arrays, one covering 5-12 μm , the other 12-28 μm . The current optical concept does not require any single detector to be located in proximity to either of the others, so the need is for three well-isolated high performance SCAs.

The "Requirement" given for each parameter in the following sections is considered a hard minimum for the mission. SCAs that do not meet the primary performance requirements (Section 3) with the array operating under the operational conditions (Section 5) will be rejected. Unless otherwise stated, all requirements are for the beginning-of-life.

The "Goal" is clearly desirable for the ultimate scientific performance of the instrument, but is recognized to be very challenging.

"Priority" is one of several categories which provides guidance as to the level of effort which should be applied to meeting a particular *goal* (the requirement is always expected to be met):

- 1. Substantial effort and resources should be applied to meeting the goal without significantly jeopardizing other parameters.
- 2. Some effort and resources should be applied towards achieving the goal but without taking any resources away from Priority 1 parameters.
- 3. Any performance meeting or exceeding the requirement is adequate.
- 4. The requirement is desired but some performance may be sacrificed if it results in a substantial improvement for priority 1 and 2 parameters.
- N/A. Design based parameters, independent of any priorities.

2. Architectural Design Requirements

Number of Flight FPMs Req't: 3 Goal: N/A Priority: N/A

Determined by current MIRI optical system concept. ``FPM" is defined as the ``Focal Plane Module", and includes the detector, fanout board, heater, temperature sensor, connectors, shielding, and support structures.

Number of SCAs Req't: 1 per FPM Goal: N/A Priority: N/A
Consistent with current optical design. ``SCA" is defined as the ``Sensor Chip Assembly", consisting of the detector array hybridized to a readout multiplexer.

SCA Format Req't: ~1024×1024 Goal: N/A Priority: N/A
Covers the desired field of view with diffraction-limited pixels. Reference pixels may be located within, or outside of, the nominal 1024² pixel field. At least 1000×1000 contiguous pixels (minus isolated "bad" pixels) must be optically active.

Signal References Req't: See discussion Goal: N/A Priority: N/A
Non-illuminated reference pixels, columns, and/or outputs must be present to help meet the low noise requirements of this system and to aid in room-temperature testing. The specific configuration of the references is subject to trade studies by the vendor as needed to meet the total noise requirement.

Pixel Pitch Req't: 25.0 μm Goal: N/A Priority: N/A
Scaled to keep size of optics reasonable.

Fill Factor Req't: >95 % Goal: 100% Priority: 4
Maximizes signal/noise, minimizes inter-pixel effects.

Number of Outputs (per SCA) Req't: 4 Goal: ≤ 4 Priority: 4

Must be consistent with current single-point-failure and redundancy goals. Number of outputs could be used as a trade for pixel readout rate to meet frame time requirement if there is a considerable performance benefit. Reference pixels are to be read through these outputs; a separate (fifth) DC reference output (if proposed) will not count against this total.

Electrical Redundancy Req't: See discussion Goal: N/A Priority: N/A

A redundant electrical configuration at the SCA level (for clocks, biases, outputs, and contacts) is desirable to reduce the potential loss of a MIRI channel from single-point electrical failures. At this time, four outputs and two bond pads per signal are required as a minimum implementation. This implementation will be revisited as the MIRI system design becomes more mature.

Partial Readouts Req't: See discussion Goal: N/A Priority: 3

Subarray observations (~256×256 pixels) of bright objects and time-variable phenomena are required. Each output will read out an equal number of pixels. Burst-clocking through unused pixels is a minimum requirement – more desirable is a mode where unused pixels do not need to be clocked at all.

Detector Material Req't: Si:As Goal: N/A Priority: N/A

Only material consistent with desired wavelength coverage from JWST Level 1 science requirements.

AR-coating Req't: optimize to application Goal: N/A Priority: 2

Desire AR coatings to optimize performance for each of the 3 SCAs. Each will have an appropriate coating to address the role of that particular detector in the optical system. The imager will have a coating optimized for the 5-12 μm range without degrading longer wavelength performance. The short-wavelength (5-12 μm) spectrometer SCA will likely use the same coating as the imager SCA. The long-wavelength (12-27 μm) spectrometer SCA will have a coating optimized for peak sensitivity in this range.

3. Primary Performance Requirements

Total SCA Noise Req't: < 10 e- rms Goal: < 2.5 e- rms Priority: 1

Defined only for the SCA for an assumed Fowler=8 readout mode. Allows photon-noise-limited imaging observations at all wavelengths. Maximizes signal/noise. Defined to be the quadrature sum of contributions from read noise, shot noise from dark current, shot noise from glow, 1/f variations, etc. To enhance observational efficiency, it is strongly desired that the read noise values consistent with the stated noise totals be achieved with the minimum number of samples, and/or in the minimum overall time. Given the baseline 1000 sec exposure time and 3 sec frame time constraints, the design will optimize read noise performance by trading numbers-of-samples against pixel time, or other variations, to achieve the stated requirement and goal noise levels. Noise data may be obtained by frame subtraction (spatial variation) or per-pixel sampling (temporal variation) techniques, as appropriate, and validated. Furthermore, these requirement and goal SCA noise values have been chosen to accommodate anticipated electronics and cable noise contributions, so as to maintain 12 and 3 e-, respectively, as system-level requirements and goals for noise.

Read noise Req't: Goal: Priority:

Unspecified to allow latitude in focal plane design and operating point, but is a component of the total noise.

Dark current Req't: Goal: Priority:

Unspecified to allow latitude in focal plane design and operating point, but is a component of the total noise. As guidance, consider the following background estimates. With a 10% bandpass filter centered at 5 μm (and reasonable assumptions about instrument throughput), we expect about 1 e-/s photocurrent from the Zodiacal background; at 10 μm , it will be nearly 100 e-/s;

while at 25 μm , the telescope background may generate a few thousand e-/s. The requirement is, therefore, <1 e-/s, driven by the short wavelength needs. The goal of zodi-limited performance with $R=100$ spectroscopy, finds an order of magnitude lower photocurrent, so the dark current goal is <0.1 e-/s. For the highest resolution spectroscopy ($R \sim 2000$), the photocurrent will be as low as 0.005 e-/s. The shot noise associated with the dark current in a 1000 s integration should be held at levels comparable to (or less than) the read noise.

QE (Imager/SW)	Req't: > 40 % (5-6 μm), > 60% (6-12 μm)	Goal: > 70%	Priority: 1
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Maximizes signal (and signal/noise). Also, consistent with QEs achieved by candidate technologies with suitable AR coatings. QE is defined to be the number of electrons collected per photon incident on the surface (includes internal efficiency and AR coatings). This requirement shall be met at all specified wavelengths with an internal gain $G = 1$, and under the operational conditions listed in section 5. The imager and the short-wavelength (SW) half of the spectrometer require the best possible performance in the 5-12 μm range. This requirement does not apply to the long-wavelength spectrometer SCA.

QE (LW)	Req't: > 70% (12-26 μm)	Goal: > 80%	Priority: 1
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Maximizes signal (and signal/noise). Also, consistent with QEs achieved by candidate technologies with suitable AR coatings. QE is defined to be the number of electrons collected per photon incident on the surface (includes internal efficiency and AR coatings). This requirement shall be met at all specified wavelengths with an internal gain $G = 1$, and under the operational conditions listed in section 5. The long-wavelength (LW) half of the spectrometer requires the best possible performance in this range. This requirement does not apply to the imager or short-wavelength spectrometer SCAs.

OE at 26-28.2 mm Req't: N/A Goal: > 5% Priority: 4

Some response at the ground state H₂ rotational line is desired, but it is a goal only. No response is *required*, particularly if it negatively impacts the dark current performance.

4. Secondary Performance Requirements

Well Capacity	Req't: $> 1 \times 10^5$ e-	Goal: $> 2 \times 10^5$ e-	Priority: 3
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Defined to be the saturation voltage divided by the capacitance. Consistent with mission objectives for dynamic range and for widely ranging background fluxes. Could possibly trade against read noise if it were advantageous to the final S/N.

Pixel Operability	Req't: > 99%	Goal: > 99.9%	Priority: 2
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For a given pixel to be operable, it must simultaneously meet all the requirements in the primary performance parameters in Section 3, operating under the conditions listed in section 5.

Bad Pixel Clusters Req't: < 5 Goal: 0 Priority: 3

A cluster is defined as a group of 3 or more pixels, adjacent to each other, not meeting the criteria listed above under "pixel operability". The adjacent pixels may be in a cluster or touching each other in a vertical, horizontal or diagonal line. No cluster may involve more than 15 pixels. Does not apply to pixels outside the minimum 1000×1000 contiguous area.

Calibration Requirement Req't: < 1% Goal: < 0.1% Priority: 1

After all calibrations are performed (for linearity, pixel-to-pixel nonuniformity, and stability), the derived flux of a source positioned anywhere on the array shall not deviate more than the calibration requirement over the time between calibrations (~ 1 week).

Linearity Req't: Stable and predictable curve Goal: N/A Priority: 4

Absolute linearity is not as important as the ability to accurately calibrate it. Shall be calibratable (and stable) from 0% to 90% of full well. A component of the total calibration requirement.

Pixel-to-Pixel Non-uniformity (pre-correction) Req't: < 10% Goal: < 1% Priority: 4

Defined as the standard deviation of the response with respect to the mean response, excluding non-operable pixels. The desire is to minimize raw sensitivity variations across the array. The absolute uniformity is not as important if it is calibratable. A component of the total calibration requirement.

Radiometric Instability Req't: < 1% Goal: < 0.1% Priority: 2

Stability must be maintained between calibration times (of order 1 week) and must be consistent with total calibration error. A component of the total calibration requirement.

Latent or Residual Images Req't: < 2% Goal: No Effect Priority: 2

Measured after exposure to a signal that fills the well to 80%. The latent value shall be obtained after a single reset following the removal of the light source.

Radiation Immunity Req't: < 4% pixels out of spec at end of 5 year mission. Goal: No effect Priority: 3

Allows some degradation but ensures that the arrays will be scientifically useful until the end of the mission. Total dose on the detector is expected to be < 5 Krad. Need to have minimal or no effect on key parameters such as responsivity, read noise, dark current. The capability to thermally anneal will be available to mitigate some effects. The anticipated anneal mode will involve raising the detector temperature to 20-30 K for a period of 1 minute.

Electrical Cross-talk Req't: < 1% Goal: < 0.1% Priority: 3

Minimize data corruption between unit cells or outputs. Implies a constraint on the settling time of the unit cells and outputs at the fastest readout rates.

Optical Crosstalk Req't: < 2.5% Goal: < 1% Priority: 3

The requirement shall be met for a point source imaged onto the detector with a focal ratio of ≤ 2 (TBR). Defined to be the brightness of the four nearest neighbors to an illuminated pixel. Intended to keep ~ 90% of light in the central pixel.

Power Dissipation (at FPA temp) Req't: < 1 mW per Mpixel Goal: < 0.1 mW per Mpixel Priority: 2

Measured at full speed (3 sec readout). Must be able to drive the cables specified in the Observational/ Environmental Conditions section.

5. Observational/Environmental Conditions

Minimum Frame Time Req't: <3 sec Goal: < 1 sec Priority: 2

Set by the background rate from a 25 μm broadband ($R=3.5$) observation to avoid saturation (and still be able to do CDS readout). Also related to pixel readout rate, number of outputs, and pixel dimensions. Shorter frame time desired as goal to observe brighter objects. Current value limited by power budgets for data conversion (A/D) electronics and settling time of SCA.

Pixel Readout Rate Req't: Goal: Priority:

Not specified. Can be traded with number of outputs to meet frame time requirement, though the expectation is that the readout rate will be ~ 10 $\mu\text{s}/\text{pixel}/\text{output}$.

Maximum Single Exposure Time Req't: > 1000 s Goal: N/A Priority: 2

Must be stable over this timescale to meet the total noise specs (e.g. $1/f$ noise). Maximum time is set by ability to accept approximately 5% of array pixels affected by cosmic events (assumed cosmic event flux of $5 \text{ s}^{-1} \text{ cm}^{-2}$).

Cosmic Ray Pixel Upsets Req't: < 10% of all pixels Goal: < 4% Priority: 3

Estimates derived from detailed analysis of clusters of pixels affected, in SIRTf proton irradiation experiments. Fraction of pixels above total noise specification after a 1000 sec integration in a cosmic ray flux of $5 \text{ s}^{-1} \text{ cm}^{-2}$. See <http://jwst.gsfc.nasa.gov/cgi-bin/pubdownload?Id=570> for information on JWST radiation environment.

Current/Capacitance Drive Capability

Req't: TBD

Goal: N/A

Priority: 1

The warm readout electronics will be located approximately 4 meters from the SCA. The SCA output must be capable of delivering a signal with good integrity over this distance through a cable with an anticipated impedance of order 40 Ohms, 30 pF per meter. External cryogenic circuits located on the focal plane may be considered if the SCA output FETs cannot drive the signal without undue amounts of glow.

Operating TemperatureReq't: $\geq 6.9\text{K}$ Goal: $> 8\text{ K}$

Priority: 1

The SCA must be able to meet the total noise budget at 6.9 K. Our desire is that the noise budget will be met at temperatures significantly higher than this, perhaps as high as 8 K. This temperature is the anticipated value obtained from Arrhenius plots needed to achieve $\ll 0.01\text{ e-/s}$ dark current.

Temperature stability

Req't: 20 mK rms

Goal: 10 mK rms

Priority: 2

The cooler/SCA mount is being designed to provide this level of stability at the detector. SIRTf also chose these levels. Stability may be mitigated by use of reference pixels and accurate temperature monitoring.

Contamination

Req't: Class 100 (TBR)

Goal: N/A

Priority: N/A

The SCA must be maintained in a Class 100 environment after final cleaning to meet the instrument contamination requirements.

Vibration

Req't: 100 g

Goal: N/A

Priority: N/A

The detector shall be designed to withstand a quasistatic acceleration of 100 g. This is equal to the base acceleration expected of the instrument with an amplification factor of 5 and should be sufficient to ensure that the detector will not require modification as the structural analysis becomes more mature.

6. Appendices

Abbreviations

- A/D analog-to-digital converter
- AR anti-reflection
- CDS correlated double sample
- DC direct current
- e- electron(s)
- FET field effect transistor
- FPM focal plane module--SCA+fanout board+mounting assembly
- JPL Jet Propulsion Laboratory
- JWST James Webb Space Telescope
- LW long wavelength
- MIRI Mid-InfraRed Instrument
- N/A not applicable
- QE quantum efficiency
- R resolution
- Req't requirements
- rms root-mean-square
- S/N signal-to-noise ratio
- SCA sensor chip assembly--detector material + readout multiplexer
- Si:As Silicon doped with Arsenic
- SIRTf Space Infrared Telescope Facility
- SW short wavelength
- TBR to be reviewed

Facility Requirements

Following are JWST requirements upon the instrument providers (i.e. JPL for MIRI) that will be of interest to the MIRI detector provider. Rather than duplicate a number of applicable documents, the relevant issues have been excerpted here, **and are meant as guidance only**. These requirements will evolve over the next few months as the observatory becomes better defined, and the specific requirements upon the detectors will be derived at that time. The detectors shall be manufactured in a manner consistent with these requirements.

Issues from the JWST General Interface Requirements Document (GIRD, JWST-IRD-000779), rev 4:

5.0 Mechanical Interfaces

Requirement: All interfaces shall be specified in the international system of units.

8.4.4 Unannounced Removal of Power

Requirement: Unannounced removal of power shall not cause damage or degraded performance to the Instrument.

8.7 Radiation Environment

Requirement: The Instrument shall be designed to operate after exposure to the radiation environment associated with low earth orbit, and during and after exposure to the radiation environment associated with transfer to and operation at L2.

Rationale: The expected radiation environment is detailed in JWST-RPT-000453, Radiation Environment for the James Webb Space Telescope (JWST web page, download document #570)

9.1 Contamination Control Requirements

Requirement: At all times, the Instrument environment shall be maintained at a minimum cleanliness level of class 10,000 or better.

Requirement: As a baseline, surface particulate contamination shall be Level 300 and surface molecular contamination shall be Level A, per Product Cleanliness Levels and Contamination Control Program, MIL-STD-1246, or better, at launch.

Issues from the JWST MIRI Unique Interface Requirements Document (UIRD, JWST-IRD-000782), rev 3:

13.0 Environmental Requirements

Exceptions: None

Additions: Add the following sections:

13.1 Random Vibration

Table 13-1 and Table 13-2 below provide the random vibration levels to which the instrument components shall be exposed during testing. Protoflight test duration shall be 1 minute for each axis. Prototype qualification test duration shall be 2 minutes.

Table 13-1. Random Vibration Test Levels

Vibration Test Levels Protoflight Components	
Frequency	Acceleration Spectral Density (G²/Hz)
20	0.026
20 to 50	+6 dB/oct
50 to 800	0.16
800 to 2000	-6 dB/oct
2000	0.026
Overall	14.1 Grms

The acceleration spectral density (ASD) level may be reduced for components weighing more than 25 Kg according to:

$$\text{dB reduction} = 10 \text{ LOG}(W/25)$$

$$\text{ASD}(50 \text{ to } 800\text{Hz}) = 0.16 \times (25/W)$$

Where W = component weight in Kg

The slope shall be maintained at ± 6 dB/Oct for components weighing up to 65 kg. Above that weight, the slopes shall be adjusted to maintain an ASD level of 0.01 G²/Hz at 20 and 2000 Hz.

For components weighing over 200 Kg, the test specification shall be maintained at the level for 200 Kg

Table 13-2. Random Vibration Workmanship Test
Components Minimum Workmanship
Random Vibration Levels

Frequency	Acceleration Spectral Density (G^2/Hz)
20	0.01
20 to 160	+3 dB/oct
160 to 250	0.08
250 to 2000	-3 dB/oct
2000	0.01
Overall	7.4 Grms

The plateau acceleration spectral density (ASD) level may be reduced for components weighing between 25 Kg and 200 Kg according to the component weight (W) up to a maximum of 9 dB as follows:

$$\text{dB reduction} = 10 \text{ LOG}(W/25)$$

$$\text{ASD(plateau) level} = 0.08 \times (25/W)$$

Where W = component weight in Kg

The sloped portions of the spectrum shall be maintained at plus and minus 3 dB/oct. Therefore, the lower and upper break points, or frequencies at the ends of the plateau become:

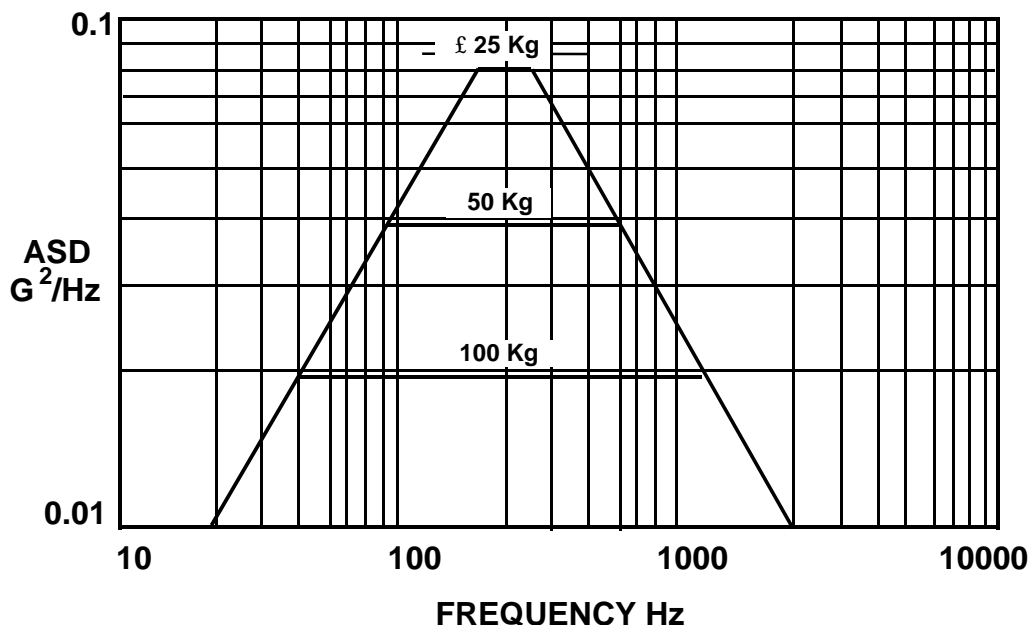
$$F_L = 160 (25/W)$$

F_L = frequency break point low end of plateau

$$F_H = 250 (W/25)$$

F_H = frequency break point high end of plateau

The test spectrum shall not go below 0.01 G^2/Hz . For components whose weight is greater than 200 Kg, the workmanship test spectrum is 0.01 G^2/Hz from 20 to 2000 Hz with an overall level of 4.4 Grms.



13.2 Sine Vibration

The Instrument shall be subjected to protoflight/qualification sine vibration test levels specified in Table 13-3 and Figure 13-1 in each of three orthogonal axes. During this test the instrument shall be in the launch configuration. There shall be one sweep from 5 Hz to 50 Hz for each axis. The protoflight sweep rate shall be 4 oct/min except in the frequency range of 25-35 Hz, where the sweep rate shall be 1.5 oct/min. For prototype testing, the sine vibration levels shall be the same as the protoflight levels and the sweep rates shall be reduced by a factor of two to 2 oct/min and 0.75 oct/min respectively.

Table 13-3. Sinusoidal Protoflight/Qualification Test Levels

Frequency	Amplitude/Acceleration
5 to 18 Hz	Displacement = 12 mm (double amplitude)
18 to 50 Hz	8 G peak

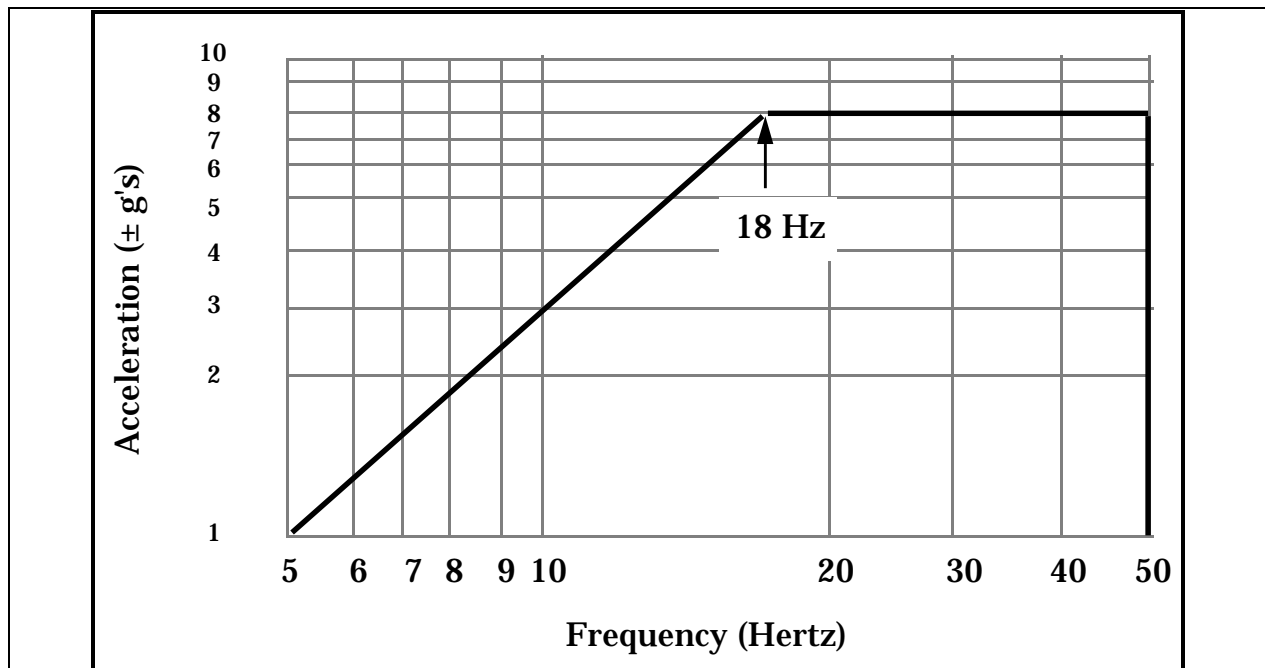


Figure 13-1. Sinusoidal Protoflight/Qualification Test Levels

13.3 Static Loads

Instrument flight hardware shall be designed to withstand a maximum acceleration of 0.015 g on orbit without permanent degradation of performance.

13.4 Shock

The Instrument shall be designed to meet performance requirements following exposure to the externally induced shock environment specified in Figure 13-2. Instruments shall be designed to survive without permanent performance degradation a peak of 1200 G's. Testing of externally induced shock will be conducted at the spacecraft level, instrument level testing is not required.

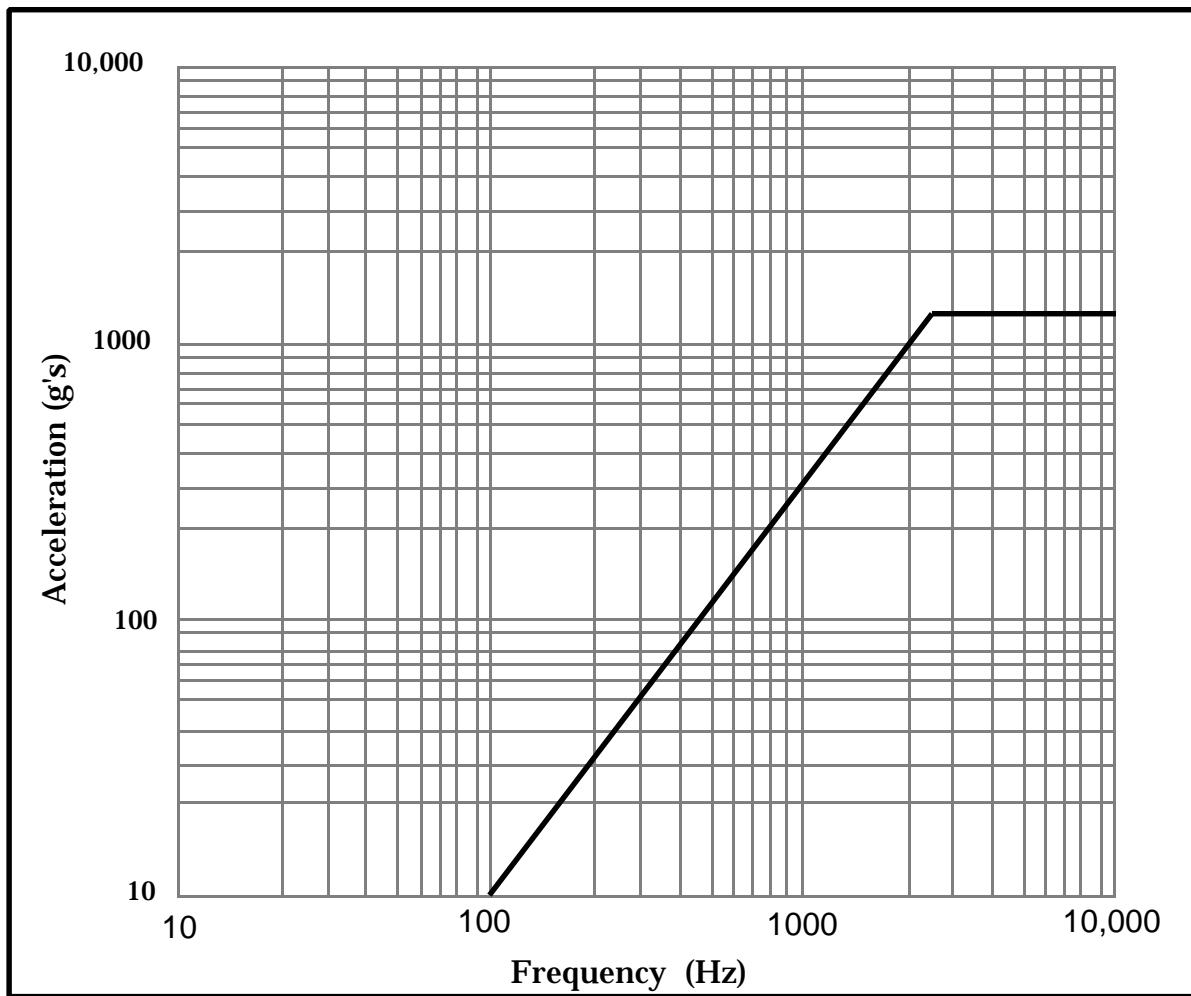


Figure 13-2. Shock Spectrum (Q=10)

13.5 Acoustics

13.5.1 Acceptance Level Acoustics

The acceptance acoustic levels shall be as defined in Table 13-4.

13.5.2 Qualification/Protoflight Level Acoustics

The qualification/protoflight acoustic levels shall be as defined in Table 13-4 increased by 3 dB.

Table 13-4. Acceptance Acoustic Levels

One-Third Octave Center Frequency (Hz)	Noise Level (dB) ref: 0dB = 20μPa
31.5	TBD
40	TBD
50	TBD
63	TBD
80	TBD
100	TBD
125	TBD
160	TBD
200	TBD
250	TBD
315	TBD
400	TBD
500	TBD
630	TBD
800	TBD
1000	TBD
1250	TBD
1600	TBD
2000	TBD
2500	TBD
3150	TBD
4000	TBD
5000	TBD
6300	TBD
8000	TBD
10000	TBD
Overall	TBD
Acceptance/Protoflight Duration: One Minute Prototype Qualification Duration: Two Minutes	